A Wearable Guidance System Incorporating Multiple Sensors for Visually Impaired Persons

Jin-Hee Lee[1], Dongho Kim[2], and Byeong-Seok Shin[1]

[1] Department of Computer Science and Information Engineering, Inha University, 100 Inha-ro, Nam-Gu, Incheon, Korea
jhlee07@outlook.com, bsshin@inha.ac.kr
[2] The Global School of Media, Soongsil University, 369 Sangdo-Ro, Dongjak-Gu, Seoul, Korea
cg@su.ac.kr

Abstract. We propose a wearable system that helps visually impaired persons walk to their destination. Once we choose a destination, our system computes a path and guides us using marker data detected by the camera in buildings. It employs positioning data from GPS receiver outdoors. Simultaneously, it exploits multiple ultrasonic sensors to avoid obstacles lying in the path. In addition, we propose a correction algorithm for GPS data that considers speed to reduce the positioning error and deploy a map- matching algorithm when a user breaks way from the correct path. We evaluate complex structure in front of the user with patterns and determine an avoidance direction by analyzing these patterns.

Keywords: Visually Impaired Person, Guidance System, Wearable Computer.

1 Introduction

Most visually impaired persons have difficulty recognizing their current position and direction. Therefore, supplementary positioning and guidance services are very important. These services involve updating one's position and orientation, while they are traveling an intended route; when they become lost; they reorient and reestablish a route to the destination. In last decades, a variety of portable or wearable navigation systems have been developed to assist visually impaired persons during navigation indoors or outdoors, but few can provide dynamic interactions and adaptability to changes. Systems for visually impaired persons can be classified into three main categories: ETA (Electronic Travel Aids), EOA (Electronic Orientation Aids), and PLD (Position Locator Devices) [1]. ETA is a device that transforms spatial information of the environment conveyed through another sensory modality. EOA is a device that provides orientation prior to, or during travel. It can be external to the user, or can be carried by the user. PLD is a device that includes GPS receiver, European Geostationary Navigation Overlay Service (EGNOS), and so on [1].

Our system is categorized as ETA. It enables us to walk safely to our destination because ultrasonic sensors scan the complex scene and an embedded camera detects

James J. (Jong Hyuk) Park et al. (eds.), *Future Information Technology*,
Lecture Notes in Electrical Engineering 309,
DOI: 10.1007/978-3-642-55038-6_85, © Springer-Verlag Berlin Heidelberg 2014

the markers to compute the direction to destination indoors. In addition, it provides path-finding features, as localization and navigation using GPS and magnetic compass sensor outdoors. We propose an optimal layout of ultrasonic sensors that uses a minimum number of sensors covering a maximum range.

The rest of the paper is structured as follows. We will give a brief review of related work in section 2, and explain our system in section 3. Experimental results are presented in section 4. Finally, we conclude our work in section 5.

2 Related Work

ETA can be implemented as a portable system. It uses ultrasonic or laser sensors to detect obstacles, and exploits a CCD camera to acquire images and to find a pathway with image processing techniques. The representative ETA systems are GuideCane [2], CyARM [3] and so on [4, 5]. However, they require heavy computation, and take much time to get environmental information surrounding users such as distance, direction, and height of objects. In addition, they require much training. Another method is to use various sensors of ETA that combines range data with information acquired from mobile robots. MELDOG [6] Walking Guide Robot [7], and so on [8, 9] are categorized as EOA systems. However, avoidance direction changes frequently, since they do not consider that the human body trembles while walking. Also, the robots can only support horizontal movement and its mobility is much more restricted than is the case of wearable systems.

We are mostly interested in ETA that includes more specifically obstacle detection systems, in addition to guidance systems. These can be categorized depending on how the information is gathered and how this information is given to the user. The National Research Council's guidelines for ETA are listed [10]. We designed our system based on these requirements.

3 Wearable Computer System Considering Spatial Context

In this section, we explain our system that guides the user to the destination with marker position and orientation in a building. In addition, our system helps a user to arrive at the destination using positioning data from GPS receiver and magnetic compass sensor outdoors. It uses an ultrasonic sensor array to detect and avoid obstacles.

We gather data from an ultrasonic sensor array, marker camera, GPS receiver, and magnetic compass sensor. They are transmitted to a wearable computer. As depicted in Fig. 1, the indoor guidance system is composed of two modules: marker recognition and obstacle avoidance (grey). The right column of Fig. 1 represents the flowchart of the outdoors navigation system composed of positioning and tracking module and obstacle detection module (grey). These steps are detailed in the next subsections.

3.1 Obstacle Detection Technique Using Ultrasonic Sensor Array

One of the important things to recognize forward space with range sensors is to arrange the sensors efficiently to cover a maximum range with a minimum number of sensors since a sensor has physical characteristics such as coverage and maximum

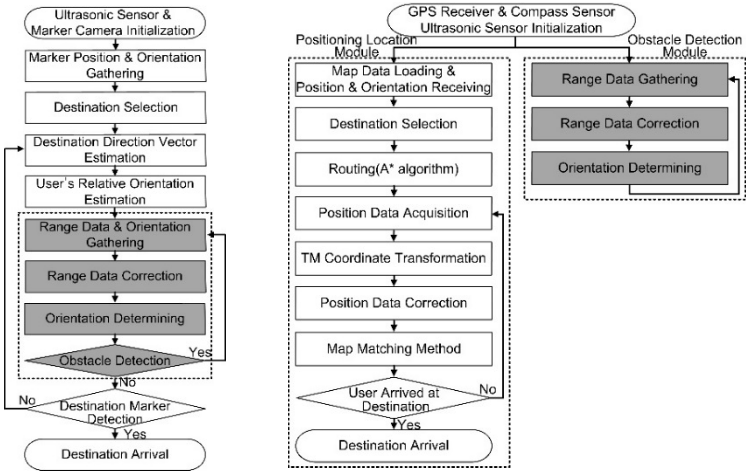

Fig. 1. Procedure for safe guidance indoors (left) and outdoors (right)

detection range. The sensor array should be designed not to be influenced by the motion of the arm or upper body while walking. In addition, it is important to make the sensor array detect obstacles quickly and precisely.

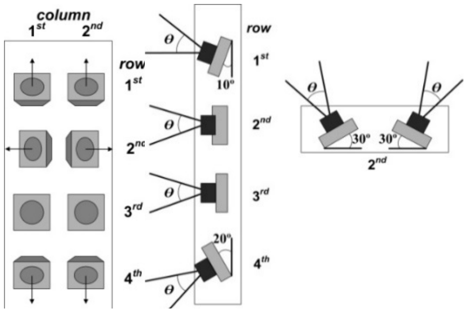

Fig. 2. Example layout of ultrasonic sensors and geometry covering forward space

Each sensor has a direction and coverage of a conic shape that does not overlap those of neighboring sensors and acquires range data for its direction, as shown in Fig. 2. Eight sensors are arranged in four rows. One row is made up two sensors. Sensors of the top row detect objects hazardous to the user's head, those of the second and third row detect frontal obstacles, such as a wall or furniture, and those of the bottom row recognize small obstacles on the floor. We evaluate H_f of the height of frame, where the user's height is H and the sensing range of an ultrasonic sensor is D_{range}. Θ denotes the beam angle of each sensor and γ indicates a tilting angle threshold by changing H_f, as shown in equation 1. The target area is defined as an area of any shape in the 2D plane to cover the sensor array, as described in Fig. 3. This guarantees high-speed and accurate range sensing, since it scans a scene immediately, as depicted in Fig. 3 (in the case of the sensing range is D_{range}).

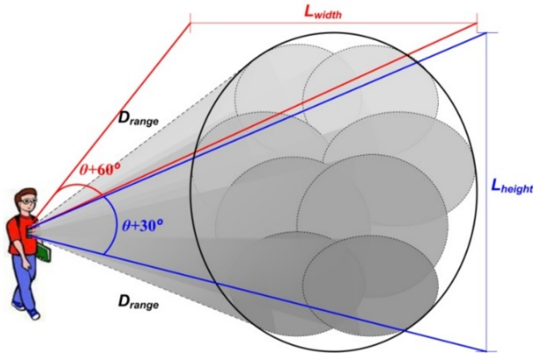

Fig. 3. Scanning coverage of sensors in our system (Scan range of ultrasonic sensor is D_{range}.)

$$D_{range} \times \sin\{\frac{\theta}{2} + (20° + \gamma)\} \leq H_f \leq D_{range} \times [\sin\{\frac{\theta}{2} + (20° + \gamma)\} + \sin\{\frac{\theta}{2} + (10° + \gamma)\}] \quad (1)$$

The next step is to determine the optimal direction of avoidance by analyzing the range data. Previous methods for path generation have an issue in demanding much computation to generate local and global maps in the preprocessing step. A navigation method should be simple to make a decision of optimal direction in real time with a small amount of computation to assist a user's walk-through on a low performance mobile computing device. The four sensors of the second row and third row detect obstacles in front of the user. We consider the range data acquired from them and represent spatial information as patterns of the range data. The range data are classified into four cases: *danger* (less than 100 cm), *warning* (100~130 cm), *adequacy* (130~200 cm), and *unconcern* (more than 200 cm). We can define 256 (=4^4) cases and form the corresponding input range data from the four sensors into 256 cases.

3.2 A Target Guidance Using Optical Marker

We attach makers to the ceiling to identify the current position and orientation. Our system selects the direction to the destination by recognizing the identifier and direction of the marker with the camera. We can estimate the relative orientation by calculating the direction vector from the current position to the destination. The camera detects markers as a regular square, and finds feature points. The makers comprises 12×12 blocks; they can represent 256 cases. The markers are detected by the camera and their patterns are transmitted to the wearable computer. The values are interpreted and compared to the predefined marker's ID. A marker is composed of a unique design and white patterns on a black background to reduce the load processing image [11].

We determine the walking direction by estimating the orientation vectors of the user, detected marker ID and orientation. We have to consider the following issues in this system. We determine the correspondence between the attached position of the marker and the previously stored local map of rooms. In addition, it is important to

decide the marker size, since the camera should hold at least one of the marker in its field of view at any time. We use multiple markers with the same ID for fast detection. However, even though we use several markers, the camera may not detect markers in some circumstances. We employ a method using the direction of the previously detected marker to resolve the problem. We estimate the orientation vector for the user as the sum of orientation vector of the destination marker detected in the previous frame and the user's avoidance direction vector. We regard this vector as the decided orientation until the camera detects a new marker. We keep the current direction as the dot product of marker orientation vector and previous direction vector less than pre-defined threshold. Therefore, we can reduce errors due to a user's trembling. We evaluate the angle using the dot product value of these vectors.

3.3 Outdoor Navigation System Incorporating Sensors

We can recognize the position and orientation of the user as data gathered from a GPS receiver and magnetic compass sensor outdoors. The user selects a destination that is one of the stored POI (Point Of Interests) lists in a map in advance. Then, the system guides the user to the destination using the A* algorithm available in searching optimal path [12]. We get longitude and latitude, as well as walking speed and heading degree from NMEA0183 protocol data of GPS receiver. However, we use a magnetic compass sensor simultaneously to acquire the user orientation, since the received heading values are inaccurate in many cases. We can reduce GPS position error by considering the walking speed of our user. Then, we assume 4.0 km/h as the speed outdoors through repeated experiment. We presume the error value as 1 m/sec when threshold is more than the difference between the current received position and previous value. In addition, our system computes the average of the previous position values, including current position, and it finds the nearest position of the user in the stored POI list. We have to predefine the bounds when we map for a visually impaired person.

The next step is to search an optimal path for a visually impaired person using the A^*algorithm that is a widely known path-finding method. Our system loads the stored landmarks and POIs, and informs the user via voice messages. The user selects a destination in the POI list. In addition, wherever GPS data is not received when a user is located in narrow alleys, we employ a concept of satellite-based navigation combined with dead reckoning. This is a guidance method of determining walking direction with current direction data of the magnetic compass sensor and the previous received GPS position data.

We made the prototype of system. The main processing of our system is performed on an Xhyper-PX270 based embedded system equipped with RS-232C Bluetooth sensor controller and vibrator controller. The input device is a keypad with Braille type buttons. The output is represented as a series of voice messages or vibration patterns through an earphone and vibration jacket. In addition, marker information and GPS data are processed in an embedded ARM10 processor. Fig. 4 shows our system prototype. We made a sensor frame using hard leather to fix the ultrasonic sensors and to minimize motion or distortion between sensors. In addition, we attached vibrators into the jacket for the conveniences of the user's perception. We generated a camera frame using hard leather to fix the camera on the shoulder to detect the marker. Furthermore, we developed a cross-bag for the user's convenience, simultaneously.

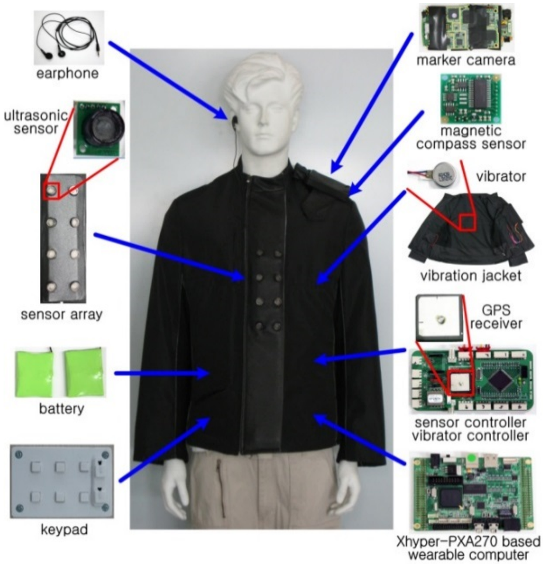

Fig. 4. System prototype

4 Experimental Results

Based on the layout, we experimented with differing heights of obstacles to confirm the ultrasonic sensor arrangement and effectiveness. Fig. 5 shows the results of detection rate by obstacle height and the user's walking speed. The sensors of the top row detected more than 90% of hazards to the user's head and the sensors of the bottom row recognized more than 80% of small obstacles (about 10cm high) on the floor. In addition, the sensors of the second and third row detected more than 95% of the obstacles in front of the user. However, the sensors did not detect obstacles when the user walks more than 1.3 times faster than ordinary pace. A visually impaired person can safely walk in places where there are established obstacles, such as a notice board and a signboard, even narrow hallway, according to the experimental results.

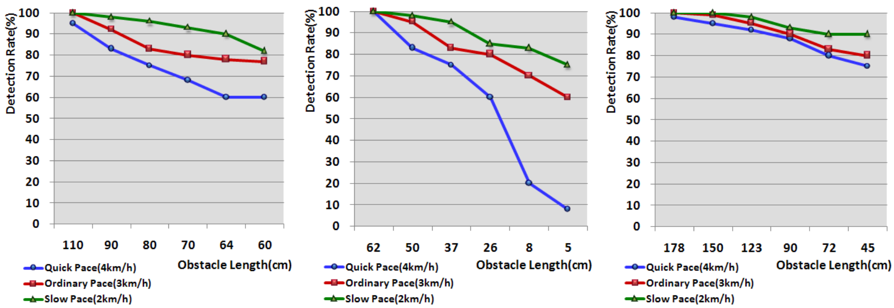

Fig. 5. The results for detection rate of the top row sensors (left), bottom row sensors (middle), and middle rows of sensors (right)

Second, we experimented with different-sized markers to determine the optimal size, while maximizing the recognition rate of a camera. Fig. 6 describes the experimental environment and shows the results. In Fig. 6, the *s*-axis represents marker size and *h*-axis denotes the distance from camera to marker. We can usually determine the optimal marker size is 20 cm×20 cm, since the height from ground to ceiling is within 350 cm and the camera view angle is 45°. We use multiple markers with equal IDs and the interval between markers is about 10~15 cm. These are considered to be the camera view angle and walking speed of a handicapped user. The result showed a user arrived at the destination safely at 3 km/h.

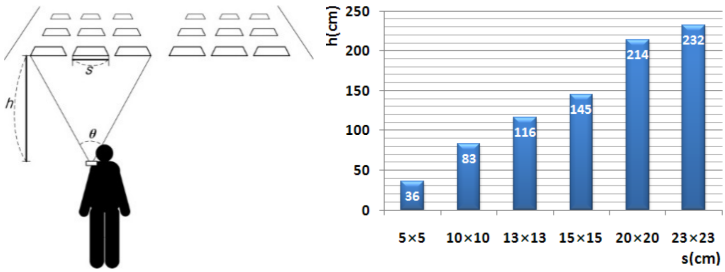

Fig. 6. Experimental environment (left) and results depending on marker size (right)

Finally, we tested the performance of our system in an outdoor environment. Several trials were conducted in different operating conditions to investigate the performance of each module of the system. The paths are classified into four cases, according to the width and complexity of the road: *narrow road* (less than 3 m), *wide road* (more than 3 m), *simple path* (less than three intersections), and *congested path* (more than three intersections). We performed four experiments: only using ultrasonic sensor array, exploiting ultrasonic sensors and GPS receiver, applying our system with ultrasonic sensors, GPS and compass sensor, and lastly normal vision at 3 km/h. The our system achieved a high success rate of about 53% if they walked along a path 200 m long on a wide and simple road. Therefore, we can improve the success rate by re-searching for a new path every 200 m, in the case of a long path. The proposed system of an equipped GPS receiver and magnetic compass sensor improved the walking speed from a minimum 18% to maximum of 28% compared to the previous system using only a GPS receiver, and success rate of 55%. In addition, the user safely walks to the destination at 1.5 km/h.

5 Conclusions

The main role of the guidance system is to quickly capture environmental data from various sensors and map the extracted and processed content onto available user interfaces in the most appropriate manner. We implemented the guidance system for a visually impaired person. Once the user chooses a destination, our system computes a path and guides the user using marker data detected by the camera in buildings and employing position data from a GPS receiver outdoors. Furthermore, it exploits multiple ultrasonic sensors to avoid obstacles lying in the path. Walking directions are

transferred to the user as voice messages or vibration patterns. Therefore, our system helps users to arrive at their destination safely without help from others. Our future work will focus on implementing a more flexible system that utilizes the advantages of wearable technologies and easily customized to those.

Acknowledgement. This work was supported by the IT R&D program of MKE/KEIT. [10035243, Component based Design Theory and Control Kernel for CPS].

References

1. Dakopoulos, D., Bourbakis, N.G.: Wearable obstacle avoidance electronic travel aids for blind: a survey. IEEE Trans. Syst. Man. Cybern. 40(1), 25–35 (2010)
2. Borenstein, J., Ulrich, I.: The GuideCane: A computerized travel aid for the active guidance of blind pedestrians. In: Proceedings of the IEEE International Conference on Robotics and Automation, pp. 1283–1288 (1997)
3. Ito, K., Okamoto, M., Akita, J., Ono, T.: CyARM: an alternative aid device for blind persons. In: Conference on Human Factors in Computing Systems, pp. 1483–1486 (2005)
4. Shim, H.M., Lee, J.S., Lee, E.H., Hong, S.H.: A study on the sound-imaging algorithm of obstacle information for the visually impaired. In: International Conference on Circuits/Systems, Computers and Communications, pp. 389–392 (2002)
5. Magatani, K., Sawa, K.: Development of the navigation system for the visually impaired by using optical beacons. In: The 23th Annual International Conference for the IEEE Engineering in Medicine and Biology Society (2001)
6. Tachi, S., Komiyama, K., Abe, M.: Electrocutaneous communication in seeing-eye robot (MELDOG). In: Proceedings 4th Annual Conference IEEE Engineering in Medicine and Biology Society, pp. 356–361 (1982)
7. Kang, J.H., Song, B.S., Yu, K.H., Yoon, M.J.: Walking guide robot with tactile display and 3D ultrasonic sensing system for the blind. In: The 21st International Technical Conference on Circuits/Systems Computers and Communications (2006)
8. Divelbiss, A.W., Wen, J.T.: A path space approach to nonholonomic motion planning in the presence of obstacles. IEEE Trans. Robotics and Automation 13(3), 443–451 (1997)
9. Hu, H., Gu, D., Brady, M.: Navigation and guidance of an intelligent mobile robot. In: EUROBOT 1997: Second Euromicro Workshop on Advanced Mobile Robots, pp. 104–111 (1997)
10. Blasch, B.B., Wiener, W.R., Welsh, R.L.: Foundations of Orientation and Mobility, 2nd edn. AFB Press, New York (1997)
11. Fiala, M.: ARTag Revision 1:A fiducial marker system using digital techniques. NRC/ERB-1117, pp. 1–47 (2004)
12. Hart, P.E., Nilsson, N.J., Raphael, B.: A formal basis for the heuristic determination of minimum cost paths. IEEE Trans. Systems Science and Cybernetics 4(2), 100–107 (1968)